

## APPENDIX C PRINCIPLES OF OPERATION

1. Overview. This section reviews the principles of thermal desorption system operation. The discussion emphasizes components of desorption systems which are similar regardless of the manufacturer. Specifics of individual components and operation will vary.

2. Materials Handling and Pretreatment. Pretreatment is dependant on both the type of contaminated material and treatment system utilized. Pretreatment for the contaminated material feed consists of two categories:

- particle size adjustment;
- dewatering.

Particle size adjustment is included in material handling activities. Materials handling includes the management of soil excavation and materials preparation prior to thermal treatment, and backfilling and dust control after thermal treatment.

The success of thermal desorption is dependant on proper materials preparation and handling prior to treatment. The contaminated material must be conditioned to a size and consistency required by the selected desorption process. Several desorption technologies have size and consistency limitations and are designed to accommodate a homogeneous feed stock.

The materials handling operation of a thermal desorption process may include one or more of the following components:

- Contaminated material excavation and transport to and from the thermal desorption system;
- Particle size reduction/sorting for removal of oversized and non homogeneous materials (via screening, shredding, crushing, blending);
- Removal of excessive moisture content by use of a pretreatment dewatering operation (evaporation, filtering, drying, centrifuge, thickening, chemical addition) to produce a suitable filter cake;
- Material stockpiles are used to synchronize the desorption process, to provide continuous feed, and to provide a sampling location;

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- Control of fugitive emissions with the use of dust suppressants, negative air pressure systems, foams or covered shelters.

Materials handling must be carried out properly to comply with handling, storage and disposal regulations and contaminant specific health and safety requirements. Excavation should be conducted in a manner to prevent cross contamination. The area and volume to be excavated and treated must be established by the design team including the survey and investigative data. Materials involved in handling operations include contaminated treated materials and treated materials. Material handling is a very important component of a successful thermal desorption remedial action. The design engineer and construction manager must pay particular attention to this design and operation component of a thermal desorption technology. Control of runoff is critical to maintenance of the excavation site. Measurement and payment is generally based on in-situ measurement of volume.

2.1 Material Excavation and Transport. Standard heavy construction excavation equipment used for the removal of large volumes of contaminated material from a remediation site. Equipment typically used includes the following:

- Dragline - Crane operated excavator bucket used to dredge soils below surface depth and far reaches and sludge from lagoons, ponds or pits;
- Backhoes - Used for surface or subsurface excavation of soils and sludges;
- Mudcat - articulated, tracked vehicle/equipment used for moving wet sludge like material in a swamp or lagoon type area; and
- Heavy Earthmoving Equipment - Include excavators, bulldozers and dump trucks used for excavation and transport. Common types of earth moving equipment are summarized in Table C-1.

Positive displacement pumps (e.g., air driven diaphragm, progressing cavity) may be used to transfer high density, abrasive or high viscosity sludges. Sludges can then be dewatered in a dewatering technology such as a filter press prior to thermal treatment.

TABLE C-1  
Earth Moving Equipment

Type	Description	Application
<u>Prime Movers</u> Crawler Tractors	Track type prime mover 40-500 HP	Used with mounted bulldozers, rippers, winches, cranes and side booms
Wheel Tractors	Range from small rubber tired units to large diesel powered types	Small units used with scoops, loaders and backhoes. Large units used for propelling wagons, scrapers and bulldozers
<u>Crawler Type Devices</u> Bulldozers-Crawler Type	Crawler tractor with a front mounted blade. Straight, angling and tilting type blades are available.	Pioneering access roads, boulder and tree removal, and short haul earth moving in rough terrain. Also push-loads self propelled scrapers and used with rear mounted rippers to loosen firm material.
Loader-Crawler Type	Track type prime mover with front mounted movable bucket. Capacities from 0.5 to 4 cubic meters (0.7 to 5.0 cubic yards).	Digging ditches, loading trucks and hoppers, and placing, spreading and compacting earth.
<u>Wheel Type Devices</u> Bulldozers-Wheel Type	Four wheel drive, rubber tired tractor with hydraulically operated front mounted blade.	Push loading self propelled scrapers, grading cuts, spreading and compacting fill and drifting loose material on firm ground for distances up to 150 m (500 feet).

TABLE C-1 (cont)  
Earth Moving Equipment

Type	Description	Application
Loader-Wheel Type	Four wheeled rubber tired prime mover with front mounted hydraulically operated shovel. Often called a Pay loader. Capacities from 0.4 to 15 cubic meters (0.5 to 20.0 cubic yards).	Handling and loading materials of all kinds on firm surfaces.
Scrapers-Tractor Drawn	Four wheeled rubber tired trailers used with crawler tractors. Capacities from 5 to 20 cubic meters (7 to 27 cubic yards).	Loading, hauling, dumping and spreading earth. One way moving up to 300 m (1,000 feet) or on terrain unsuitable for self propelled scrapers.
Scrapers-Self Propelled	Scraper with integral self propelled two or four wheel tractor. All wheel drive self loading types also available.	High speed earth moving.
Bottom Dump Wagons	Available in capacities to 135,000 Kg (150 short tons).	Used in place of scrapers on large wheel tractors or trucks for hauling earth, sand or gravel over long distances.
End Dump Trucks	Heavy duty, diesel powered truck with rear dump body. Capacities of 11,000 to 320,000 kg (12 to 350 tons).	Used for hauling and dumping hard and abrasive shovel loaded materials.

Source: Marks' Standard Handbook for Mechanical Engineers, 8th Edition

2.2 Waste Size Classification. Particle size distribution of contaminated material is a physical characteristic that influences the applicability of desorption. Soils are generally classified according to the Unified Soil Classification System (USCS). The four major divisions of the USCS are: (1) coarse grained; (2) fine-grained; (3) organic soils; and (4) peat. Coarse grained soils can be classified according to grain size distribution, whereas, fine grained soils are generally related to their plasticity.

The standard for classifying soils involves the use of a 74µm sieve. Coarse grained soils have more than 50% of their material captured by a 74µm sieve. Fine grained soils have more than 50% of their material pass through a 74µm sieve (Troxler, et al., 1993).

Finely grained soils, such as silts, may become entrained in the off-gas stream of a thermal desorption system and not achieve proper residence time at the required temperature. Between 5 to 30% of fine grained soils fed into a direct fired thermal desorber may become entrained in the gas stream, and between 1 to 5% of the fine grained soils fed into an indirect fired thermal desorber may become entrained in the gas stream. The extent of particulate entrainment is a function of the average particle size of the soil, the off gas velocity through the unit and the type of material transport mechanism. Gas velocities within a direct fired unit are typically between 1.5 to 3 meters (5 to 10 feet) per second and between 0.3 to 1 meter (1 to 3 feet) per second within an indirect fired unit. Estimates of entrainment are dependent on system design, however, entrainment is proportional to the percentage of finely grained soils and higher off gas velocities through the system. In these cases, the entrained material may be recycled back to the thermal desorber (typically through a cyclone) with a corresponding loss in treatment capacity (U.S. EPA, 1994).

2.2.1 Screening. Contaminated materials excavated from a remediation site may vary widely in aggregate size. Initially, large size debris is separated from the other contaminated materials. The smaller debris and materials can then be directed to a screening mechanism to further separate debris greater than the maximum treatment size from the materials. The screening process is repeated until the required particle size is achieved.

Thermal desorption systems typically require that material feed stocks be screened to a particle size of 2.5 to 5 cm (1 to 2 inches.)

A variety of screening devices are commercially available; the selection of an appropriate screening device is dependent upon the degree of screening required. A combination of one or more screening devices may be used to achieve a successive reduction in particle size. Typical screening devices include vibrating type screens, static screens and grizzlies.

Depending on the contaminated material for treatment, oversize materials may or may not have to be tested to determine if thermal treatment is required. This is a function of the nature and viscosity of the contaminants and the permeability of the oversized material. For example if a site contained 80,000 cubic meters (100,000 cubic yards) of soil contaminated with PCBs that required treatment and 95% of the particle size of this soil was smaller than 5 cm (2 inches), then 4,000 cubic meters (5,000 cubic yards) of oversize material may need to be crushed to a size less than 5 cm (2 inches) prior to treatment. The issue is whether or not this oversized material requires treatment. If the contaminated material to be treated consists of soil and rocks and does not contain landfill debris or organic materials such as wood, paper or other materials that readily absorb contaminants, then the oversize material may not require treatment. The design team should consult the regulators and determine whether or not such material requires thermal treatment or whether a less expensive solution would meet the cleanup standards.

Fuel contaminated sites with large quantities of soil  $2.27 \times 10^7$  kg (25,000 ton) have been treated for \$65/1000 kg (\$59/ton) while smaller sites less than  $4.53 \times 10^6$  kg (5000 ton) have been awarded at \$440/1000 kg (\$400/ton). Presented below are examples of the screening and crushing or pulverizing devices typically used on excavated materials prior to thermal treatment.

**2.2.2 Shredding.** Large sized debris and aggregate material can be pretreated with shredding equipment. Shredders typically employ two or more pairs of cutting wheel assemblies or auger blades. The wheels or blades of each pair rotate in opposite directions and the debris or aggregate material is fed in between each pair and is broken up with shearing action. Shredders are available to handle a wide variety of materials including some clays (and abrasive clay clumps and/or cohesive clay balls), metal wood, rubber and concrete.

Debris such as metal drums and rubber tires may be processed through these devices (note: if the drums contain a hazardous waste then they would need to be disposed off-site).

2.2.3 Crushing. Large aggregate material can be pretreated with the use of crushing devices that reduce the size of the material by direct impact. Hammer mills are devices used to reduce the particle size of soft materials. Impact crushers use rotating hammers or bars to break up materials containing impurities and cracks. Tumbling mills employ a rotating drum filled with balls, rods, tubes or pebbles to reduce the size of rocks and other materials. Pulverizers reduce the size of large aggregate such as concrete, stone or glass prior to further crushing. Pulverizers also separate reinforcing bar from reinforced concrete.

2.2.4 Blending. Mechanical blending is a pretreatment option used to handle contaminated materials with the following elevated parameters: moisture content, plasticity, and/or high concentrations of volatile organics.

The lowest moisture content at which soil will deform without shearing is known as the plastic limit. Thermal desorption of fine grained soils with moisture contents exceeding the plastic limit is extremely difficult due to plastic soils compacting into larger particles when subjected to pressure. The larger particles are difficult to heat because of their low surface area to volume ratio. Other problems associated with the treatment of plastic soils include the following.

- Difficulty in removal of debris and aggregate;
- Adherence to material handling equipment;
- Clogging the system; and
- Reducing the heat transfer efficiencies.

The moisture content of plastic soils may be decreased below the plastic limit by mixing the contaminated material with drier soil or other inert materials.

For contaminated materials with elevated levels of volatile organic concentrations, mechanical mixing may be used to equalize volatile organic loading and optimize the feed rate to the thermal desorber by blending inert materials or materials of lower volatile organic concentrations (Troxler, et al., 1993).

Mechanical mixing of contaminated material is done with standard construction equipment such as backhoes, excavators, and clamshells. Blending equipment such as bladed rotating blending heads for attachment to standard construction equipment is commercially available.

2.3 Dewatering. Dewatering is a significant pretreatment for thermal desorption of contaminated material with an elevated moisture content. Moisture content of contaminated material will impact the treatment cost of thermal desorption. Moisture content is the percent by weight of water in soil, and is calculated either using a dry weight basis or a wet weight basis.

For example:

If 1 kg, (2.2 lb) of moist soil loses 0.2 kg (0.44 lb) of water when dried in a furnace, the 0.8 kg (1.76 lb) or the 1.0 kg (2.2 lb) can be used to calculate the percent weight.

0.2 kg (0.44 lb) water/0.8 kg (1.76 lb) soil = .25 or 25% water (dry basis)

or

0.2 kg (0.44 lb) water/1.0 kg (2.2 lb) soil = .2 or 20% water (wet basis)

Dewatering is a physical process used to reduce the moisture content of contaminated materials. Dewatering can fall into three categories:

- Natural dewatering which utilizes natural evaporation;
- Mechanically assisted dewatering which uses a mechanical device to physically reduce the moisture content of the contaminated material. The selection of a suitable dewatering device is dependent on materials to be dewatered. A sludge not amenable to mechanical dewatering could be dewatered on a sand drying bed. Typical types of dewatering processes include belt filter presses, recessed plate filter presses, drying beds, and lagoons; and
- Dewatering by heat addition.

The belt filter press is the most effective mechanical device used and most common technology for dewatering almost all types of solids. Since the belt filter press dewaterers solids relatively quickly, it is an effective pretreatment device for solids prior to treatment in a thermal desorption unit. A typical belt filter press consists of feed pumps, polymer feed equipment, a belt filter press, a sludge cake conveyor, and miscellaneous support systems. Depending on the type of belt press used, a feed containing 1 to 10% solids can be dewatered to 10 to 50% solids (Metcalf and Eddy, 1991).

In a plate and frame filter press, the solid is dewatered by driving the water from the sludge under high pressure.



This type of dewatering apparatus can produce a filter cake with solids concentrations ranging from 30 - 50%. A typical filter press consists of a series of rectangular plates, recessed on both sides, that are supported face to face in a vertical position with a frame. The frame has a fixed and a moveable head. Each plate is generally covered with a filter cloth. The slurry is pumped into the spaces between the plates, and pressure is applied and maintained for one or more hours. The liquid is squeezed out of the slurry and collected beneath the press (Metcalf and Eddy, 1991). Design of filter press applications is discussed in separate guidance. CEGS 11360 Plate and Frame Filter Press System is used to specify a filter press for dewatering.

Drying beds are used to dewater sludge. Drying beds fall into four categories:

- Conventional sand;
- Paved;
- Artificial media; and
- Vacuum assisted.

After drying the sludge in a drying bed, the dewatered sludge can be removed and treated in the thermal desorber. Drying beds are generally capable of providing solids ranging from 10 to 35% final concentrations. The performance of drying beds is impacted by bad weather, precipitation and low temperatures (Corbitt, 1990).

Drying lagoons can be used as a substitute for drying beds for dewatering sludges. Lagoons are not recommended for dewatering untreated sludges, or sludges with a high-strength supernatant due to their odor and nuisance potential. Lagoons are most effective in areas with high evaporation rates. Like drying beds, lagoon performance is affected by weather (Corbitt, 1990).

Relative cost effectiveness of the unit processes for dewatering and thermal desorption should be evaluated prior to design of a system for dewatering and thermal desorption. Mechanical dewatering can reduce moisture in contaminated material to 50% moisture by weight. The cost of dewatering ranged between \$22/1000 kg and \$44/1000 kg (\$20 and \$40/ton) at 1994 prices. Thermal desorption costs may double from \$165 to \$386/1000 kg (\$150 to \$350/ton) for a contaminated material containing 15-20% moisture to \$330 to \$660/1000 kg (\$300 and \$600/ton) for thermally treating a contaminated material containing 50% moisture.

2.4 Feed Hopper Systems. Feed hoppers collect pretreated contaminated materials for feed into the thermal desorber. Contaminated materials are generally loaded from the stockpile into the feed hopper by front end loader or other similar type construction equipment (Troxler, et al., 1993).

Some hoppers are equipped with a non vibratory screen at the inlet to act as a final screening device for the contaminated material. A feed screw or rotary air lock is installed below the feed hopper to meter the material into the thermal desorber. Weigh hoppers consisting of a feed hopper with weigh scale or weight sensor can be used to meter material to the desorption device. Feed hopper systems can use magnets to remove metal if the contaminated material was excavated from an industrial area.

2.5 Conveyance Systems. Conveyors are used to transport contaminated material into and treated material out of the thermal desorber. Screw type conveyors are generally used to transport the contaminated material from the outlet of the feed hopper to the inlet of the desorption device. Belt or screw conveyors are used to carry the treated material from the desorber outlet to a truck or temporary storage area. Weigh scales may be installed as part of the conveyance system to weigh the treated material prior to disposal or on-site backfilling.

The capacity of the conveyance systems selected is dependent upon the throughput capacity of the thermal desorber. Variable speed conveyors may be selected to accommodate changes in processing feed rate.

3. Desorption of Contaminants. This section discusses types of desorption units for removal of organics from solids and desorption theory.

3.1 Dryer Systems. Commercially available, dryer systems to treat organic contaminated soil include: thermal screws, rotary dryers, and conveyor furnace dryers. The mechanical design features and process operating conditions vary considerably among the various types of systems. A brief description of each of these technologies dryer systems is provided below.

3.1.1 Thermal Screws. Thermal screws are available with treatment capacities ranging from 2,700 to 13,610 kg (3 to 15 tons) of contaminated material per hour. Thermal screw systems are generally trailer-mounted. The number of trailers required depends on the size and capacity of the system - with two to four trailers being typical. Thermal screws are typically classified as low temperature thermal desorbers.

Figure C-1 is a diagram of an indirectly fired thermal screw. A typical thermal screw process contains the following major components:

- Indirectly heated screw or paddle augers;
- Heat transfer fluid heating system; and
- Treated solids cooling conveyor.

A thermal screw processor may consist of from one to four screw or paddle augers. Augers can be arranged in series to increase solids residence times, or in parallel to increase contaminated material input capacity. The auger system conveys, mixes, and heats contaminated material to volatilize the organic compounds which are then carried away via an exhaust system. Most thermal screw systems are heated by hot oil, molten salt or with process steam; some systems utilize molten salt. The heat transfer fluid heating system is fired with either propane, natural gas, or No. 2 fuel oil. The heat transfer fluid is circulated through the jacket trough in which each auger rotates. The heat transfer fluid is also circulated through the hollow auger flights and returned through the auger shaft (Troxler, et. al., 1993).

Combustion gas does not contact the waste material and normally can be discharged directly to the atmosphere without emissions control. A fraction of the flue gas from the hot oil heating system is recycled to the screw conveyor. Recycled flue gas maintains the thermal screw off gas exit temperature above 150°C (300°F) so that volatilized organics and moisture do not condense. The recycled flue gas has a low oxygen content (less than 2% by volume) and provides an essentially inert atmosphere to minimize oxidation of organics (Troxler, et. al., 1993).

The maximum temperature to be attained in the thermal screw system is limited by the temperature of the heat transfer fluid and materials of construction of the system. Hot oil heated systems can achieve feed material temperatures of up to 260°C (500°F); steam heat systems can heat soil up to 177°C (350°F) (Troxler, et. al., 1993); molten salt systems up to 370°C (700°F); electrically heated screws may be hotter.

After the treated material exits the thermal screw, water is sprayed on the treated material for cooling and dust control. The water may be mixed with the hot treated material in a screw conveyor or pugmill (Troxler, et. al., 1993).

Vaporized organics, water, and inert off-gas are drawn from the screw conveyor under an induced draft and pulled through the off-gas treatment system. A particulate control device,

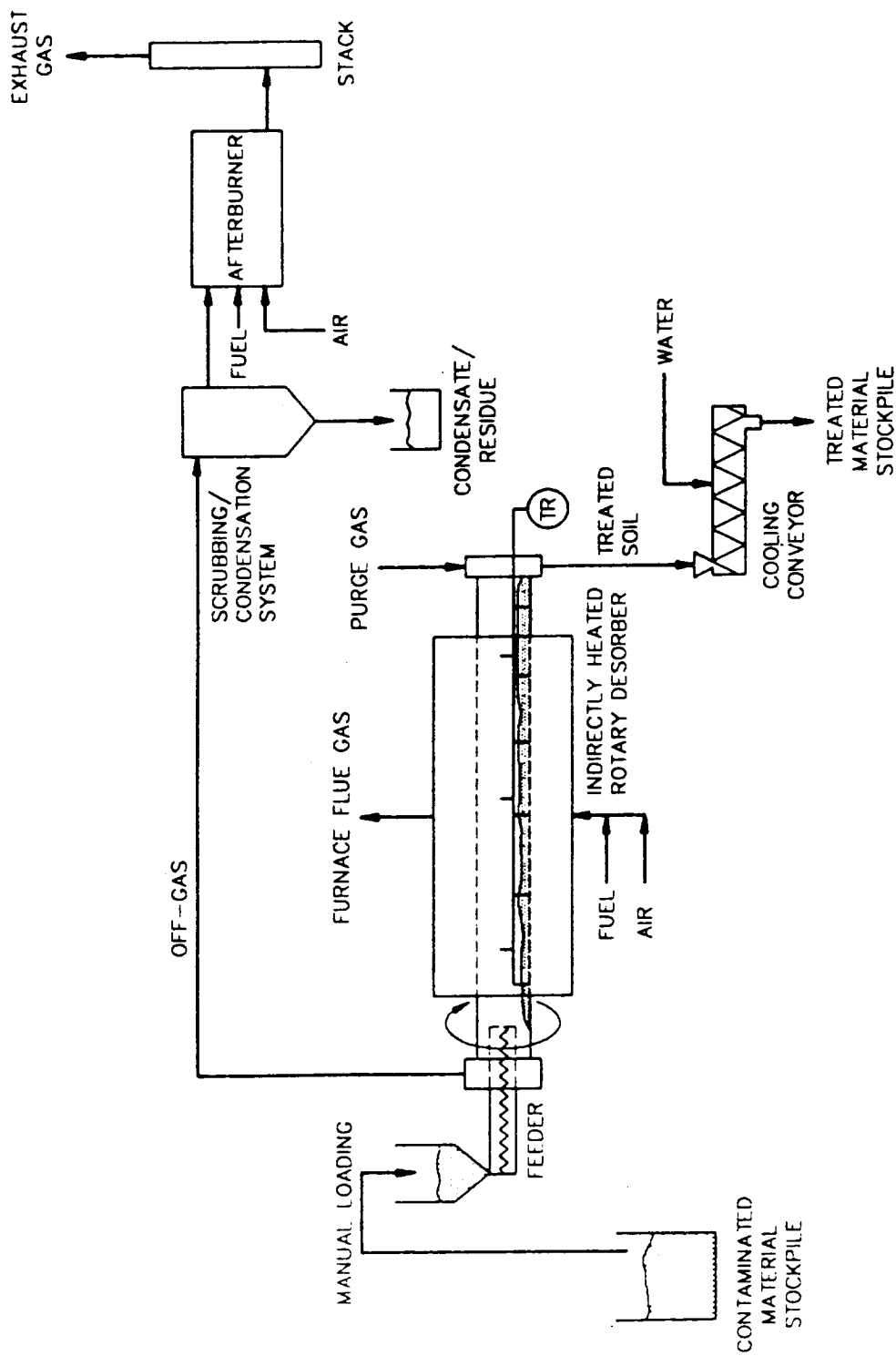


FIGURE C-1  
**TYPICAL THERMAL SCREW PROCESS DIAGRAM**

REFERENCE:

Hilsel, 1989 and Trotter et al., 1993

such as a venturi scrubber, cyclone or bag filter, is commonly used directly down stream of the thermal screw. Other devices used to control emissions from thermal desorption units include cyclones, afterburners, baghouse filters, venturi scrubbers, scrubbers and activated carbon (Troxler, et. al., 1993). Most screw use a single- or multi stage condensation system combined with other unit operations.

Off-gas volume from the primary thermal treatment unit operation of an indirectly heated, thermal screw may be a factor of 2 to 10 times less than the volume from a directly heated system with an equivalent feed material processing capacity. The corresponding exhaust treatment systems for indirectly heated thermal screws are relatively small unit operations that are well suited for mobile applications. Indirect heating systems allow processing materials with high organic content by use of inert gas blanketing which prevents oxidation of desorbed organic compounds. Thermal screws are typically used on the following compounds, solvents such as TCE, gasoline, naptha and jet fuels within a distillation temperature range of 93°C to 88°C (200 to 550°F), (Troxler, et. al., 1993).

3.1.2 Thermal Screw Pilot System. Contaminated material is fed into the soil feed hopper. The soil falls into the thermal processor. The thermal processor consists of two units, each containing four hollow screws. As the screws turn, they churn the feed material, breaking it up and pushing it from the feed end of the processor to the discharge end. In the meantime, a hot liquid (oil typically) is pumped through the inside of the screws. The constant churning of the soil and movement of hot liquid up and down the length of the screws heat the feed material and volatilizes the volatile organics. Additional heat is provided by the walls of the processor which also contains flowing hot liquid (USATHAMA Cir 200-1-5). The thermal processor heats up to a maximum of about 340°C (650 degrees Fahrenheit).

Once the volatile organics are vaporized, they flow through piping into a burner or other means of treatment, such as a scrubber or carbon adsorption system. The off gas then passes through a discharge stack monitored for volatile organics.

In the meantime, the treated material which is now virtually volatile organic-free, falls into the discharge end of the processor, where it can be put back into the excavation area. Figure C-2 provides a schematic diagram of a thermal screw pilot system.

3.1.3 Rotary Dryers. Rotary dryers are available as both mobile and stationary systems. Treatment capacities range from 4,500 to  $1.8 \times 10^6$  kg (5 to over 100 tons) of contaminated material per hour (Troxler, et. al., 1993). Rotary dryers can operate at low or high temperature. A typical rotary dryer system contains the following major process components:

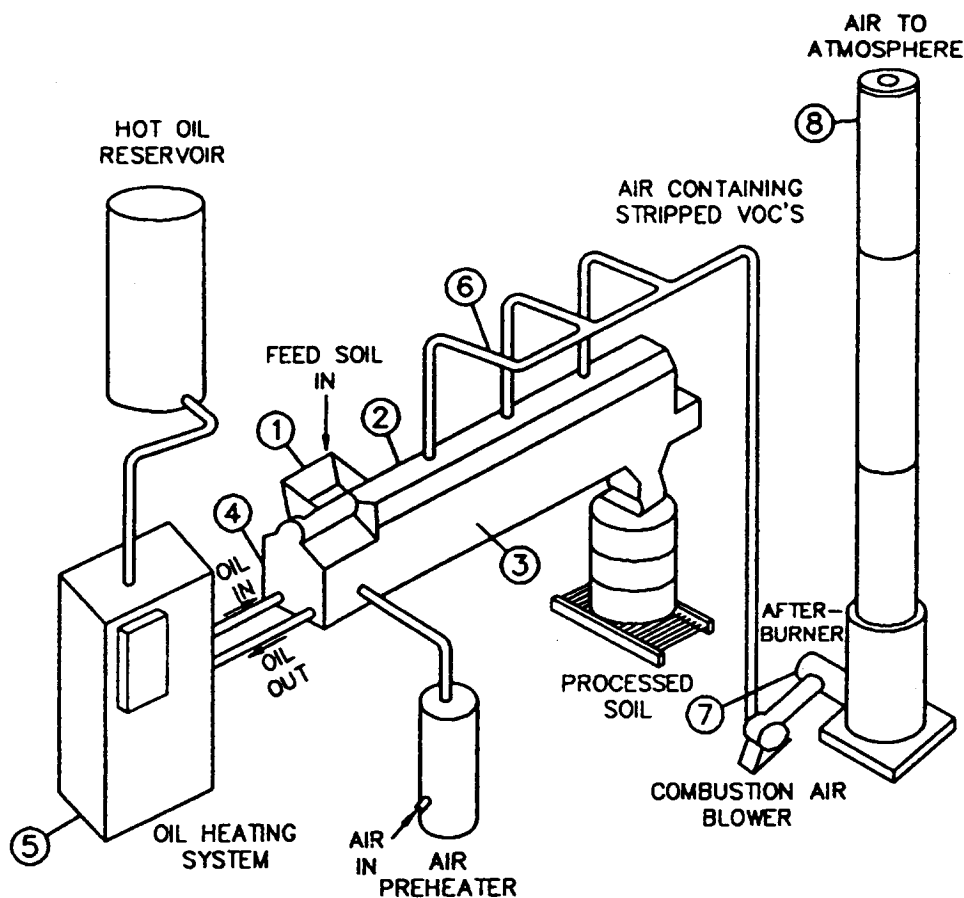
- Rotary dryer (co-current or counter current);
- Treated soil cooling system; and
- Air pollution control(cyclones, baghouse filters).

Co-current firing in a rotary dryer involves the flow of solids (contaminated material) through the dryer in the same direction as the off-gas, whereas counter-current firing is the flow of solids (contaminated material) through the dryer in the opposite direction of the off-gas. The following describes advantages and disadvantages of co-current and counter-current rotary dryer systems.

A rotary dryer system uses a cylindrical metal reactor (drum) that is inclined slightly relative to the horizontal position. A natural gas, propane or fuel oil fired burner located at one end of the dryer provides heat to raise the temperature of the feed material sufficiently to desorb the organic contaminants. Organic contaminants are removed by the off-gas. The flow of solids may either be co-current or counter current to the direction of the off-gas flow. A series of lifters inside the drum pick up the feed material, carries it to the top of the drum and drops it through hot combustion gases from the burner. The intense mixing which occurs in a rotary dryer enhances the heat transfer by direct contact with the hot gases and allows feed materials to be heated rapidly. As the drum rotates, the feed material is conveyed through the drum.

The residence time of solids in the drum is controlled by the rotational speed of the drum and the angle of inclination, and the arrangement of internal lifters. (Troxler, et. al., 1993).

The maximum soil temperature in a rotary dryer is dependant on the construction material for the dryer shell. Normally these shells are constructed of carbon steel and operate at soil discharge temperatures of 149 to 316°C (300 to 600°F). Rotary dryers are constructed of alloys which can heat contaminated materials up to a temperature of 650°C (1200°F) (Troxler, et al., 1993). After the treated material exits the rotary dryer, it is sprayed with water for cooling and dust control.



Schematic diagram of the low temperature thermal stripping pilot system:

- (1) soil feed hopper
- (2) thermal processor
- (3) hollow screw conveyor with hot fluid flowing inside
- (4) trough jacket
- (5) oil heating system
- (6) off-gas emission monitoring
- (7) afterburner
- (8) stack testing for VOC, particulates and HCl

AEC (formerly USATHAMA Cir 1-5), 1990

FIGURE C-2  
LOW TEMPERATURE THERMAL STRIPPING DIAGRAM

Counter current rotary dryers are typically followed by wet scrubbers, a cyclone, a baghouse, an ID fan, an afterburner, and a stack. The off gas temperature from a counter-current rotary dryer is limited by the material of construction of the bags in the baghouse. This temperature limitation is normally in the range of 260 to 350°C (500-660°F). A key advantage of the counter current system is that the off gas can go directly to the baghouse without adding water or air for cooling. However, because of the relatively low baghouse operating temperature, there is some potential for high molecular weight organics to condense in the baghouse and contaminate the baghouse fines or to blind the bags (Troxler, et. al., 1993). Temperature is limited to material of construction of the bags in the baghouse (if a baghouse is used). Temperatures can be higher if a wet scrubber or water quench is used.

A common equipment arrangement of co-current rotary dryer is a cyclone, an afterburner, an evaporative cooler, a baghouse, an ID fan, and a stack. Rotary dryers that operate in co-current mode discharge off gas at a temperature of 10 to 40°C (50 to 100°F) hotter than the soil discharge temperature. This results in exhaust temperatures that may range from 200 to 540°C (400 to 1,000°F). (Troxler, et. al., 1993).

3.1.4 Bed Desorption Systems. A bed desorption system is essentially a desorption system which utilizes a conveyor and a bed. The system is typically a transportable mobile unit which is transported on flatbed trailers. The capacity of this system is 4,500 to 9,000 kg (5 to 10 tons) of soil per hour. The conveyor furnace uses a flexible metal belt to convey contaminated material through a primary heating chamber. A 2.54 cm (one inch) deep layer of contaminated material is spread evenly over the belt. A series of burners fire into a chamber above the belt to heat the feed. This system can heat materials to temperatures ranging from 150 to 430°C (300 to 800°F). After the treated material exits the conveyor furnace, it is sprayed with water for cooling and dust control.

The off-gas exits the conveyor furnace and is treated in an off-gas treatment system which consists of an afterburner, quench chamber, and a venturi type scrubber. Water discharged from the scrubber is used to cool the treated material (Troxler, et. al., 1993).

3.1.5 Batch Processes. Batch thermal treatment process systems can remediate soil contaminated with volatile and semi-volatile organics to below detectable limits. The process does not alter the chemical structure of contaminants, which allows the contaminants such as petroleum to be recovered and recycled. In many cases, the process is



considered to be an enhanced vacuum extraction system, and can operate without air monitoring controls. On HTRW sites activated carbon or quench, cyclone, and wet scrubbers have been added as necessary. Depending on the type of contaminant and the moisture content of the soil, batch treatments can remediate as much as  $51 \times 10^3$  kg (56 tons) of soil per hour, per unit. The process is especially suitable for use in clay media. Petroleum hydrocarbons, chlorinated solvents, pesticides, PCBs and mercury have been treated successfully. Arsenic in a chloride or organically bound form also can be handled. The process recently has been tested as a method for extracting volatiles from mixed waste (Pollution Engineering, 1994).

3.1.6 Low Temperature Volatilization System. The Low Temperature Volatilization System is a batch type system used to thermally treat contaminated soil at exit temperatures. The primary thermal treatment component of this system is a natural gas or propane fired, countercurrent rotary dryer with internal flights. Contaminated material is fed into the dryer where the internal flights lift and spill the soil through the hot gas stream. Treated material from the dryer exits into a discharge auger where it is water-cooled. The cooled soil drops onto a stacking conveyor and is conveyed to a temporary stockpile. The air pollution control system consists of a baghouse, an afterburner quench, and packed bed scrubber. Entrained particles in the thermal desorber off gas are removed by the baghouse. Volatilized organic compounds from the thermal desorber off gas are destroyed in the afterburner. Following the afterburner, a wet air pollution control system is used to remove HCl and Cl<sub>2</sub> present in the off-gases. A block flow diagram of the Low Temperature Volatilization System is shown in Figure C-3. The block flow diagram begins where soil feed and auxiliary fuel are introduced into the thermal desorber and then traces the off-gases through the air pollution control system.

3.2 Waste Contact with Heat Transfer Surface. The volatilization of the organics contaminants and water from the soil is primarily dependent upon the physical and chemical characteristics of both the soil and the organic contaminants.

3.2.1 Volatilization of Organics. Volatilization processes within this document are focused primarily on contaminants. Toxic metals present in contaminated material may also be volatilized and are subsequently partitioned between the treated material and the off gas. (In general, materials with toxic metals as the principal contaminants are not amenable to thermal desorption).

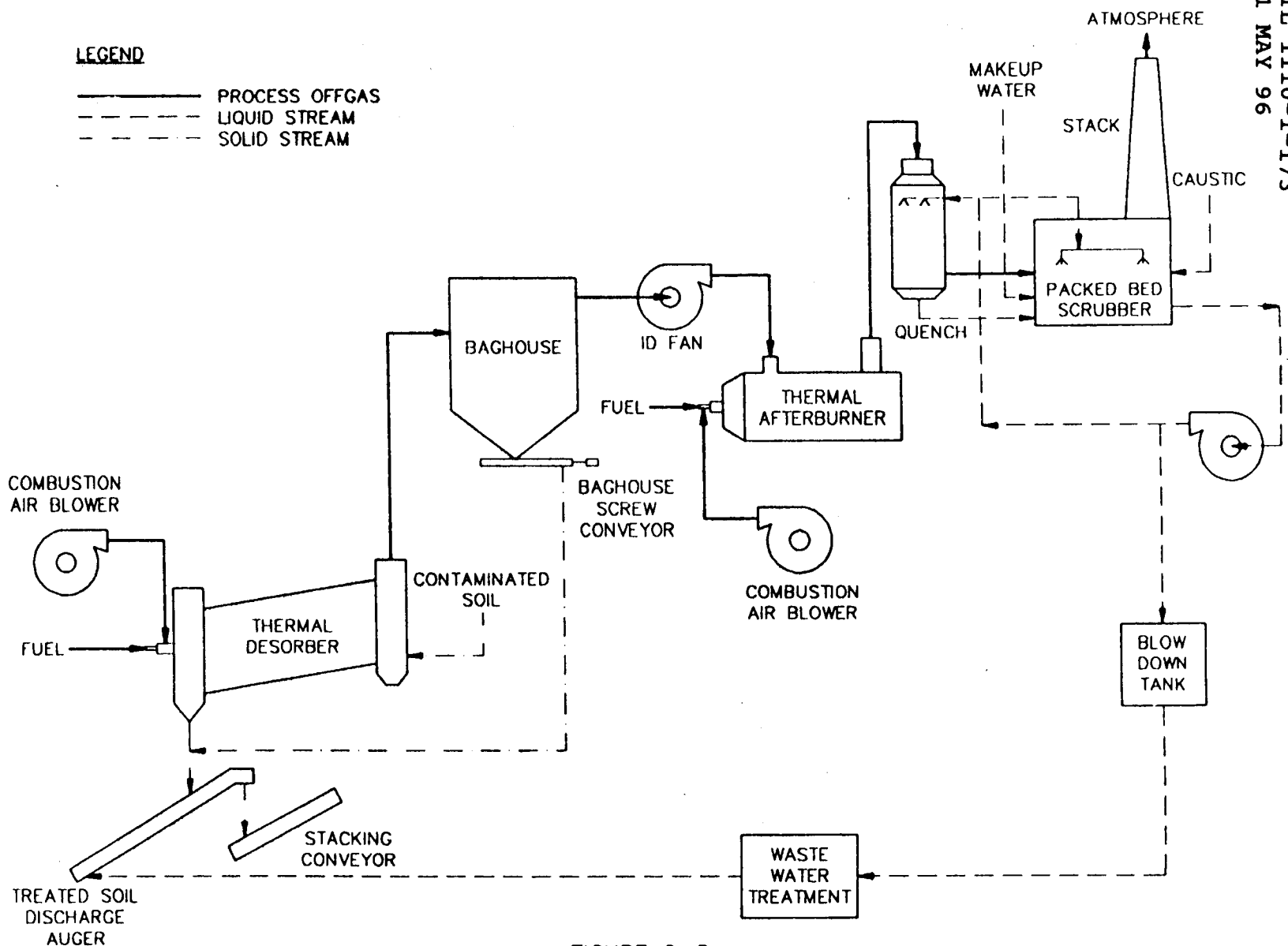


FIGURE C-3  
LTVS BLOCK FLOW DIAGRAM

Volatilization of organics is dependant on the following physical and chemical characteristics:

- Soil temperature: the soil temperature is a function of the moisture content of the soil, heat capacity, particle size of the soil, and the heat transfer and mixing characteristics of the thermal desorption device.
- Exposed contact surface between soil and air or other carrier gas.
- Contaminant Characteristics: the contaminant characteristics of most importance include the vapor pressure of the organic, and the concentration of the organic in the soil.

### Soil Temperature

Soil characteristics such as size, moisture and plasticity affect the desorption of contaminants from soil.

A major factor affecting the temperature of the soil is its specific heat or its thermal capacity. The moisture content tends to buffer the soil from rapid changes in temperature.

The particle size of the soil indirectly impacts the volatilization of organics. Fine-grained soil particles such as silts and clay may become entrained in the process gas and pass through a thermal desorption device without adequate residence time to allow desorption. The organics adhere to fine particles and as a result become entrained in the gas stream. This phenomenon impacts both the performance of the desorber and the air emissions. Typically, the entrained particles are recycled back through the desorber. (Brady, 1984))

### Contaminant Characteristics

Table C-2 provides a list of physical and chemical characteristics and their relevance to thermal desorption. The vapor pressure of the organic constituent is a key parameter which influences the rate and temperature at which a contaminant is thermally desorbed. The operating temperature must be below the point where combustion can occur. The combustion of organics is a function of temperature and oxygen concentration; these parameters are controlled to prevent combustion.

Vapor pressure versus temperature curves can be used to determine the operating temperature range to desorb organics. When the vapor pressure of an organic compound is equal to atmospheric pressure, the organic compound begins to boil.

Vapor pressures of organic compounds may be found in references, such as Yaws (Yaws, 1994) or calculated. The following modification of the Clausius-Clapeyron equation (Petrucci, 1982) is useful in the calculation of vapor pressure:

$$\log (P_2/P_1) = -)H_{\text{vap}}/(2.303R)*((T_2 - T_1)/(T_1T_2))$$

where: T = is expressed in Kelvin  
h<sub>vap</sub> = heat of vaporization expressed in Kj/mol  
P = is expressed in mm Hg  
R = 8.314 Jmol<sup>-1</sup>K<sup>-1</sup>

Use of this equation requires the calculation of the temperature for small changes in pressure (pressure difference 10 mm Hg or less) in order to remain accurate. The pressure and temperature at the boiling point of is known for most organics (pressure = 760 mm Hg). Therefore, the equation can be solved iteratively for T<sub>2</sub> for a very small difference in pressure. In the first iteration, P<sub>2</sub> should be equal to 750 mm Hg. The calculations are easily executed using a computer program or a spread sheet.

Another equation which can be used to generate vapor pressure vs. temperature information is Antoine's equation:

$$\text{Ln}(\text{VP}) = A - (B/(T+C))$$

where: Ln(VP) = the natural log of vapor pressure in mm Hg;  
A = Antoine curve fit constant  
B = Curve fit constant (in Kelvin)  
C = Curve fit constant (in Kelvin)  
T = temperature in kelvin.

Antoine's coefficients and other chemical/physical properties can be obtained from a standard source containing properties of gases and liquids.

#### Autoignition Temperature

The autoignition temperature of a substance is the temperature at which vapors ignite spontaneously from the heat of the environment. (Bodurtha, 1980) The autoignition temperature, which may be found in references such as Lange's Handbook of Chemistry, is generally significantly higher than the boiling point. For example, peat moss and highly volatile organic materials possess low autoignition temperatures and could burn in the primary chamber of a thermal desorber.

TABLE C-2  
Contaminant Characteristics

Characteristic	Reason for Potential Impact
Physical Characteristics	
Vapor pressure	Contaminant vapor pressure and contaminant removal rate increase as soil treatment temperature increases.
Boiling point	Relative indicator of degree of difficulty for volatilizing a specific compound.
Molecular weight	Boiling point temperature generally increases as molecular weight increases, therefore, molecular weight is a good indicator of the degree of difficulty of volatilizing a specific compound.
Octanol/water partition coefficient, $K_{ow}$	Measure of relative distribution of a chemical substance between organic and aqueous phases (< 1 mg/kg).
Soil/water partition coefficient, K	Measure of relative distribution of a chemical substance between solid and aqueous phases. A higher value of K represents a greater affinity for the soil.
Aqueous solubility	Potential for leaching soluble components into groundwater.
Autoignition temperature	Combustion of compounds if concentration in thermal desorber off gas is above lower explosive limit and sufficient oxygen is available to support combustion.

TABLE C-2 (cont)  
Contaminant Characteristics

Characteristic	Reason for Potential Impact
Chemical Characteristics	
Concentration of metals or organics in TCLP extract	Untreated waste may be a RCRA hazardous material.
	Treated material may be classified as a RCRA hazardous waste and require stabilization. Most likely contaminant is lead from leaded gasoline.
Concentration of metals	Stack emissions of metals are regulated on a state by state basis. Most likely metals contaminants are lead, nickel, and vanadium. Waste lubricating oil may contain a variety of metals. Some states also have criteria for maximum allowable concentrations of metals in treated soil.
BTEX	Soil cleanup criteria established by state standards.
Sulfur	Potential air emissions of sulfur dioxide are generally insignificant. Regulated on a state-by-state basis.
Nitrogen	Concentration of nitrogen oxides in thermal desorption system stack gas are generally below 100 ppmv. Stack emissions are regulated on a state-by-state basis. NOx generation could be a concern due to nitrogen content present in contaminated material (soil) and or fuels especially in direct fire units.
Organic content of soil	Highly organic soils (e.g. loam) contribute BTUs to thermal desorption system providing stronger bonds for organic contaminants requiring higher treatment temperatures
Organic gasoline additives	Residual MTBE concentration is a cleanup parameter in some states.

TABLE C-2 (cont)  
Contaminant Characteristics

Characteristic	Reason for Potential Impact
Contaminant Concentration	
Lower Explosive Limit	Maximum concentration of organics in feed material to direct fired thermal desorbers must be limited to prevent the concentration of organics in the off gas from exceeding the lower explosive limit. Maximum petroleum hydrocarbon feed concentrations for direct fired thermal desorption systems are in the range of 1 to 4 percent.
Soil treatment time and temperature.	Selection of required soil treatment temperature and residence time to meet soil cleanup criteria established by state standards.
Afterburner auxiliary fuel usage	Increasing concentration of organics in feed soil reduces afterburner auxiliary fuel requirements if an afterburner system is used. High concentrations of organics in feed soil (greater than 2 to 4 percent) may cause concentration of organics in thermal desorber exhaust gas to exceed afterburner thermal capacity.
Liquid waste disposal costs	Increasing concentration of organics in feed material increases organic liquid waste disposal costs if a condensing type off gas treatment system is used.
Source: Troxler, et al. 1993.	

Table C-3 provides boiling point, autoignition temperature and other characteristics of compounds contained in petroleum products.

Thermal desorption operating temperature is maintained below the auto ignition temperature of the organics.

This parameter could play a key role in the selection of a thermal desorption system. For example, assume that soil has been contaminated with the organics presented on Table C-3. The temperature range need to desorb the organics ranges from 0-450°C (32-838°F). The auto ignition temperature ranges from 261-562°C (502-1,044°F). Ignoring the auto ignition temperature, the operating temperature range for the desorber would be calculated using the procedure identified in the discussion on vapor pressure. At 261°C (502°F), n-hexane will burn in an oxidizing atmosphere. In order to deal with this complex waste stream, the engineer could either have multiple chambers with operating temperatures increasing or use a desorber which utilizes an inert sweep gas such as nitrogen.

Thermal desorption of a semi volatile organic compound is assisted by gas flow and can be accomplished at temperatures below boiling. Provided the partial pressure of a substance above the substrate is lower than the vapor pressure, the substance will evaporate. Rate of evaporation is slowed by operation at below boiling temperatures.

3.2.2 Application of Physical Characteristics. An initial input parameter for the thermal desorption process involves the determination of soil characteristics such as moisture content, particle size distribution and heat capacity.

The design team should develop a table containing both the boiling point and the average soil concentration data for all the organic compounds targeted for treatment. The energy required to vaporize the organics with the highest concentrations should be calculated. The first step involves determining the energy needed to heat the soil to the desired temperature.

BASIS: 1.0 kg (2.21 lb) dry soil mixed with 0.2 kg (0.44 lb) of water both initially at 20°C (68°F) is passed through a desorber. The goal is to raise the temperature of the soil to 700°C (1292°F). Specific heat of soil is 200 cal/kg°C (0.2 BTU/lb°F) and specific heat of water is 1000 cal/kg°C (1 BTU/lb°F).



TABLE C-3  
Characteristics of Compounds in Petroleum Products

Compound	Formula	Molecular Weight	Boiling Point °C (°F)	Lower Explosive Limit (% Volume)	Autoignition Temperature °C (°F)
n-Butane	C <sub>4</sub> H <sub>10</sub>	58	0 (32)	1.9	405 (761)
1-Pentene	C <sub>5</sub> H <sub>10</sub>	70	30 (86)	1.5	273 (523)
Pentane	C <sub>5</sub> H <sub>12</sub>	72	36 (97)	1.4	309 (588)
Benzene	C <sub>6</sub> H <sub>6</sub>	78	80 (176)	1.4	562 (1,044)
n-Hexane	C <sub>6</sub> H <sub>14</sub>	86	67 (156)	1.1	261 (502)
Toluene	C <sub>7</sub> H <sub>8</sub>	92	111 (232)	1.4	536 (997)
o-Xylene	C <sub>8</sub> H <sub>10</sub>	106	144 (291)	1.0	464 (867)
Ethylbenzene	C <sub>8</sub> H <sub>10</sub>	106	136 (277)	1.0	432 (810)
1,2,4-Trimethylbenzene	C <sub>9</sub> H <sub>12</sub>	120	169 (336)	NA	521 (970)
Naphthalene	C <sub>10</sub> H <sub>8</sub>	128	218 (424)	0.9	526 (979)
1-Methylnaphthalene	C <sub>11</sub> H <sub>10</sub>	142	240 (464)	NA	528 (982)

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TABLE C-3 (cont)  
Characteristics of Compounds in Petroleum Products

Compound	Formula	Molecular Weight	Boiling Point °C (°F)	Lower Explosive Limit (% Volume)	Autoignition Temperature °C (°F)
1,4-Dimethylnaphthalene	C <sub>12</sub> H <sub>12</sub>	156	268 (514)	NA	NA
Phenanthrene	C <sub>14</sub> H <sub>10</sub>	178	340 (644)	NA	NA
Pyrene	C <sub>16</sub> H <sub>10</sub>	202	404 (759)	NA	NA
Triphenylene	C <sub>18</sub> H <sub>12</sub>	228	425 (797)	NA	NA
Chrysene	C <sub>18</sub> H <sub>12</sub>	228	448 (838)	NA	NA
Perylene	C <sub>20</sub> H <sub>12</sub>	252	400 (752)	NA	NA
NA - Not Available Source (U.S. EPA, 1994)					

- The energy required to raise the temperature of the soil from 20 to 100°C (68 to 212°F) is 1.0 kg (2.2 lb) dry soil x 80°C (144°F) x 200 cal/kg°C (0.2 BTU/lb°F) = 16,000 cal (63.5 BTU).
- The energy required to concurrently raise the water associated with the soil from 20 to 100°C (68 to 212°F) is 0.2 kg (0.44 lb) water x 80°C (144°F) x 1000 cal/kg°C (1 BTU/lb °F) = 16,000 cal (63.5 BTU).
- The energy required to evaporate water is 0.2 kg (0.44 lb) water x  $5.4 \times 10^5$  cal/kg water (972 BTU/lb) = 108,000 cal (428 BTU).
- The energy required to raise the dry soil from 100 to 700°C (212 to 1292°F) is 1.0 kg (2.2 lb) x 600°C (1080°F) x 200 cal/kg°C = 120,000 cal (476 BTU).
- Thermal energy required to raise the temperature of the soil at 20% moisture from 20 to 700°C (68 to 1292°F) is 16,000 cal (63.5 BTU) + 16,000 cal (63.5 BTU) + 108,000 cal (428 BTU) + 120,000 cal (476 BTU) = 260,000 cal (1,032 BTU).

For the relatively dry soil, nearly half of the energy is used to raise the water temperature and evaporate it. The additional energy required to evaporate the organics is inversely related to the vapor pressure and directly related to the affinity of the organic material for the soil.

This information helps determine the power requirements for the system and if the unit itself can provide the energy required to raise the soil temperature.

The maximum concentration of petroleum hydrocarbons that can be treated by a thermal desorption device is dependent on gas flow through the device, the oxygen content of the off gas, the type of hydrocarbon present, and the heat input.

**3.2.3 Sweep Gas.** As discussed in previous sections, the off-gases may be inert or oxidative. An example of an inert gas is nitrogen, and an example of an oxidative gas is low oxygen content combustion gas. For direct fired units, low oxygen content combustion gas is utilized. For indirect fired units, inert gases are utilized. The maximum allowable organic content of feed material is 1 to 2% organic contents (for gasoline contamination) and up to 3 to 4% for No. 6 fuel oil contamination for an oxidative thermal desorption system (US EPA, 1994). Thermal screws and other indirect fired units may operate under an inert or very low oxygen content atmosphere.

Therefore, these types of units can accept waste with up to 50% organic compounds.

3.3 Treatment Temperature. As discussed in the previous section the thermal desorption treatment temperature is a function of several parameters:

- Moisture content;
- Heat capacity of the soil;
- Particle size of the soil;
- The temperature range which the organics will desorb; and
- The heat transfer and mixing characteristics.

As the solids progress through the reactor, they are processed in the following zones:

- Warming Zone - moist soil is heated to the boiling point of water 100°C (212°F);
- Drying Zone - soil is maintained at 100°C (212°F) until the moisture has evaporated;
- Heat Up Zone - dry soil is heated from 100°C (212°F) to the target treatment temperature; and
- Holding/Treatment Zone - dry soil is processed at or above the target temperature to desorb the organic.

The energy requirement for heating soil will significantly exceed the energy requirement for solely heating the water (without evaporating it).

4. Secondary Treatment. Thermal desorption of contaminated material generates process residuals that require secondary treatment. During the heating of contaminated material, contaminants are transferred to the sweep gas, creating an off-gas which contains particulate, vaporized organic contaminants and water vapor. Particulates are removed from the off-gas prior to off-gas treatment. In addition to the particulate matter generated, a wastewater stream is generated by the water vapor present in the off-gas which condenses in the heat exchanger.

4.1 Off-Gas Particulate Removal. Particulate matter is typically the largest emission factor (by weight or volume) generated from the thermal desorption unit. The particulate matter primarily consists of fines and dust which when entrained into the sweep gas exit the desorption chamber. The particulate matter often has organic compounds adhered to its surface which require the removal of particulate matter from the organics and sweep gas. Common control devices utilized for this process include settling chambers, inertial separators (cyclones),

impingement separators, wet scrubbers, fabric filters (bag houses), and electrostatic precipitators. Wet scrubbers, cyclones and baghouses, in combination or alone, are commonly used to remove particulate from the off-gas of thermal desorbers.

TM 5-815-1 Air Pollution Control Systems for Boilers and Incinerators provides guidance and procedures for selection of control equipment.

4.1.1 Inertial Separators. An inertial separator uses centrifugal force to separate large particles (greater than 15  $\mu\text{m}$ ) from the off gas. The smaller particles are typically removed in scrubbers and filters such as baghouses. A cyclone is the most common type of separator used for thermal desorption systems. It is a low cost inertial separator which separates particles without the use of moving parts. The performance of a cyclone separator is primarily dependant upon the particle size of the particulate. The vortex required for particle separation is created by injecting gas into the cylinder section. The particle is then propelled into the cyclone along its walls and at the point the vortex changes direction (Corbitt, 1990). The pressure drop across the cyclone is the motive force for the removal of particles from the sweep gas. Cyclone efficiency will increase with the following parameters:

- Decrease in gas viscosity (inversely proportional);
- Increase in cylinder diameter (directly proportional);
- Increase in inlet duct width or area (directly proportional); and
- Increase in density difference between gas and particulate (directly proportional).

Table C-4 provides efficiency ranges for conventional and high efficiency cyclones.

TABLE C-4  
Efficiency Range for Cyclones

Particle Size Range, $\mu\text{m}$	Efficiency Range, wt % Collected	
	Conventional	"High Efficiency"
Less than 5	Less than 50	50-80
5-20	50-80	80-95
15-40	80-95	95-99
Greater than 40	95-99	95-99
Source: Stern, 1977. Air Pollution, Vol. IV Engineering Control of Air Pollution, Academic Press, NY. Ed by Arthur Stern		

4.1.2 Wet Scrubbers. Wet scrubbers are collection/removal devices that wet particulate matter present in the off gas stream. The major categories of wet scrubbers include the following:

- Preformed spray scrubbers;
- Packed-bed scrubbers;
- Plate scrubbers;
- Venturi scrubbers;
- Orifice scrubbers; and
- Mechanical scrubbers.

Wet scrubbers use water sprays to wash the off gas free of particulate. The wash water (blowdown) would be incorporated into the wastewater stream (Corbitt, 1990). Scrubbers can also be used to remove acid gases from the off gas.

4.1.3 Fabric Filters. The most efficient device for removing particles is the fabric filter. Fabric filters have the capability of removing particles 0.3  $\mu\text{m}$  and greater. The basic design feature of fabric filter unit consists of woven or felted fabric, usually in the form of tubes (bags) that are suspended in a housing structure or baghouse. Unlike cyclones and scrubbers, this system operates with a low pressure drop. Depending upon the contaminant levels of the particulate, the collected particulate could either be added to the treated material or reprocessed through the treatment unit. Fabric filters may be coated with lime to react with acid gases.

4.1.4 Electrostatic Precipitators. Electrostatic precipitators are particle removal devices where an electric charge is imparted to a particle by exposing it to an electrostatic field of sufficient strength (3000-6000 v/cm (5080 to 7620 v/m), overall potential 20,000 to 100,000 v). The charged particle then migrates toward the oppositely charged ground collection electrode, where the charge is neutralized. Once "collected" on the electrode, the particle falls to a collection hopper under the force of gravity. Generally particles are removed from the collection or ground electrodes using mechanical "rappers", however they can also be removed by water washing.

4.2 Off-Gas Organics Treatment. After particulate removal, off-gas can be treated by condensing the contaminants into concentrated forms, burning the organic contaminants, or use of carbon or ion exchange media bed to adsorb the contaminants. Following treatment, the off-gas can be vented to the atmosphere.

4.2.1 Vapor Ion Exchange. Regenerable ion exchange systems maybe used to concentrate the off-gas prior to thermal oxidation, condensation or recovery of valuable materials.

4.2.2 Combustion. Organic contaminants can be treated by passing the off-gas through an afterburner or thermal oxidizer.

An efficient afterburner design must provide adequate dwell or residence time for complete combustion, sufficiently high temperatures for volatile organics destruction and adequate velocities to ensure proper mixing. Catalytic afterburners operate similarly except that a catalyst is used to lower the activation energy needed for combustion so that the catalytic afterburner can operate at a lower temperature.

In afterburners, the volatile organics-laden off-gas is delivered to the refractory-lined burner area by a blower. The combustible matter is thoroughly mixed with the burner flame in the upstream portion of the chamber and then passed through the remaining portion where combustion is completed. Residence times of 0.3 to 1.0 second at temperatures ranging from 538 to 871°C (1,000 to 1,600°F) are generally required. Natural gas may be used to ignite the mixture and maintain combustion temperatures. Heat recovery efficiencies vary from 35% to 70%; destruction efficiencies from 95 to 99+%.

The catalyst in catalytic afterburners are made up of platinum and its alloys, copper chromite, copper oxide, chromium, manganese and nickel. These catalysts are deposited in layers on

an inert substrate, usually honey-comb shaped ceramic. For the catalyst to be effective the active sites upon which the organic gas molecules react must be accessible. The percent LEL of the gas stream must be kept below 20% to keep the temperature below 538 to 649°C (1,000 to 1,200°F).

USACE Documents that provide additional information regarding desorption include Incinerators, General Purpose (CEGS 11181) and Remediation of Contaminated Soils and Sludges by Incineration (CEGS 02288).

4.2.3 Vapor Phase Carbon Adsorption. Contaminants in the off-gas can be collected in a vapor phase carbon adsorption system. These systems are commercially available and widely used by industry. The off-gas must be cooled, filtered and have moisture removed to below 50% relative humidity for best results prior to carbon adsorption. Data from vapor phase isotherms for the contaminants of concern is used to design and size the system. The vapor phase isotherm is the relationship between the partial pressure of the organic contaminant and the weight adsorbed by the carbon. The isotherm assumes very low moisture in the vapor phase. Vapor phase carbon systems are available in regenerable and non-regenerable units. Non regenerable units are changed in the field and the spent unit is returned to the supplier for regeneration. Regenerable units may be selected if the degree of contamination is high, and frequent changing of the carbon units is required. The type of system selected is dependant on project economics.

Note that off-gases have a relative humidity of 100% which greatly reduces efficiency and effectiveness of using carbon. Carbon capture efficiency is between 80-95%, where as combustion systems remove 95-99%.

4.3 Off-Gas Condensation. Few thermal desorption systems incorporate off-gas condensation and disposal.

Typically, in those thermal desorption systems that do condense off-gas, an inert carrier gas transports the volatilized water and organics to the off-gas handling system. The off-gases are condensed. Temperature heat exchangers are used to accomplish the condensation. The water is then separated from the organic phase. The water is sent to a wastewater treatment plant and the organics are collected and disposed offsite.



4.4 Wastewater. The wastewater generated from a thermal desorption system can be treated with conventional wastewater treatment technologies such as chemical precipitation and ion exchange for metal and inorganics removal, or carbon adsorption for organic removal and general polishing. If necessary, wastewater may require additional treatment using oil/water separation techniques such as coalescence and dissolved air flotation technologies. Since metals and organics are generally not volatile, they are not expected to be in wastewater fraction at large concentrations. Metals precipitation may be ineffective if metal concentration is low. The type of treatment is dependant upon the contaminants in the wastewater and the discharge limits either established by a regulatory agency or treatment authority (local wastewater treatment plant).

TM 5-814-3 Domestic Wastewater Treatment and TM 5-814-1 Sanitary and Industrial Wastewater Collection - Gravity Sewers and Appurtenances provide design guidance for wastewater treatment systems.

4.4.1 Liquid Phase Carbon Adsorption. Wastewater generated by the off-gas condensation process is typically treated by using a carbon adsorption process. Adsorption of organics from wastewater is a treatment technology which is now widely accepted. The acceptance in part is based on its long history of effectively removing organic contaminants from groundwater and wastewater systems.

The first consideration in the design of an activation carbon system is carbon selection. The waste water stream must be characterized, the contaminants identified, quantified, and treatment goals established. A number of activated carbons are commercially available, and selection is usually determined by laboratory or pilot testing of the particular carbon. The two most important variables in carbon system design are contact time breakthrough characteristics, and flow requirements. Breakthrough is defined as the point at which the contaminant concentration exiting the adsorber exceeds the treatment goal. Contact times may be varied by changing bed depth at constant flow, which alters the time to breakthrough and may be determined experimentally with column tests.

Downflow fixed bed absorbers are the simplest and most widely used design for water treatment application. The water enters the top of the absorber, is distributed across the packed bed, and is collected at the bottom of the vessel. The

fixed bed can either be gravity or pressure driven. A fixed bed pressure absorber is usually an ASME coded steel pressure vessel with corrosion resistant lining.

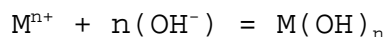
Further information on carbon adsorption can be obtain from the following document(s):

EM 1110 1-501, Design Manual for Wastewater Treatment  
Evaluation Criteria Guide for Water  
TM 5-814-8, Evaluation Criteria Guide for Water Pollution  
Prevention, Control and Abatement Programs  
CEGS 11215, Liquid Phase Activated Carbon Adsorption Systems

4.4.2 Precipitation. When the wastewater contains metal contaminants, precipitation or ion exchange can be employed to remove the metals from the wastewater.

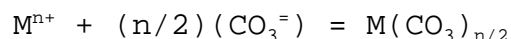
Table C-5 lists the metals and the precipitation technology used to remove the metal. As indicated on Table C-5, metals can be removed from water as one of several salts. The various forms of precipitation are described briefly below. Figure C-4 shows the solubilities of selected metal ions as hydroxide or sulfide metal salts.

Hydroxide precipitation generally uses quicklime ( $\text{CaO}$ ) or hydrated lime ( $\text{Ca(OH)}_2$ ) as a source of a hydroxide ion which raises the pH of the water to the optimum pH for precipitation. This optimum pH varies with the target metal. Caustic soda ( $\text{NaOH}$ ) can be used instead of lime; the reagent costs are higher, although less sludge may be generated. A general form of the hydroxide precipitation reaction is:



Note that the solubility depends on the presence of chelate in the water, as well as the pH.

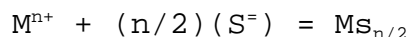
Carbonate precipitation generally uses sodium carbonate or calcium carbonate to convert metals into an insoluble metal carbonates. The general form of the carbonate precipitation reaction is:



The treatment efficiency depends on the pH of the water. Carbonates are much less soluble than the corresponding hydroxides and as a result, lower concentrations of the target metals can be achieved in the treatment plant effluent. For

certain metals (i.e., lead and cadmium), carbonate sludge has more desirable settling and dewatering characteristics than the hydroxide sludge (Patterson, 1985).

Sulfide precipitation results when a sulfide ion reacts with a metal ion to form an insoluble metal salt. A simple form of sulfide precipitation is written below:



Sulfides are less soluble than the corresponding hydroxides and carbonates, and lower concentrations of the target metals can be achieved in the treated water. Two processes used in sulfide precipitation are:

- Insoluble sulfide precipitation - sulfide is added as a slightly soluble iron sulfide slurry;
- Soluble sulfide precipitation - sodium sulfide or sodium hydrosulfide is added. With this process overdosing of sulfide compounds can produce toxic hydrogen sulfide gas; therefore, the reaction tanks should be covered and off gasses should be treated prior to discharge to the atmosphere.

4.4.3 Liquid Ion Exchange. Liquid ion exchange is a process of exchanging selected dissolved ionic compounds with a set of substitute ions. The exchange occurs on a synthetic or natural resin. The target compounds are removed from the wastewater through direct contact with the resin. Once the resin is saturated with the targeted ions, backwashing/ regeneration of the resin is necessary to remove these ions from the resin. Regeneration solutions generally consist of acids and bases. Hence, the waste regenerant solution will typically contain a concentrate of dissolved metals and have an undesirable pH.

Liquid ion exchange requires suspended solids kept below 50 mg/l, and total dissolved solids kept below 5000 mg/l. Iron, manganese, calcium, and high organic concentrations may permanently foul the resins. Large organic molecules may clog pore species between in the resin.

Ion exchange is an expensive water treatment technology which includes a waste stream requiring additional treatment and/or disposal. It is generally not recommended. However, if stringent discharge limits are imposed by a regulatory agency, ion exchange may be necessary to meet inorganic discharges.

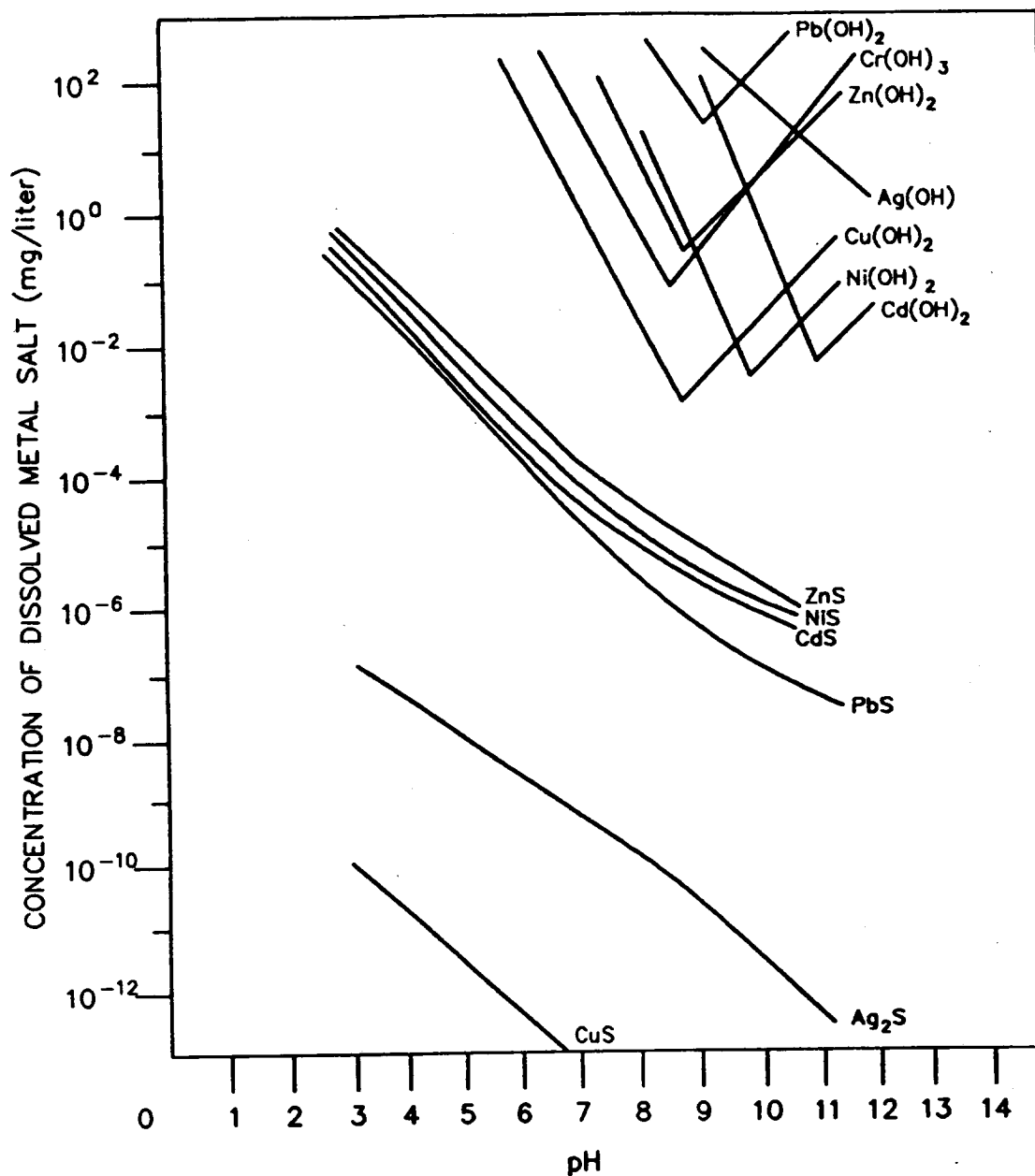
TABLE C-5  
Effective Types of Precipitation for Selected Metal Ions

Metal Ions	Hydroxide Precipitation	Sulfide Precipitation	Carbonate Precipitation
Antimony			
Arsenic	x	x	
Beryllium		x	T
Cadmium	x		x
Chromium	x	x	
Copper	x	x	
Lead	x	x	x
Mercury		x	
Nickel	x	x	x
Selenium			
Silver	x	T	
Thallium		T	
Zinc	x	x	T
Iron	x	x	
Manganese	x	T	

The effluent concentrations reported assumes the oxidation states of the metal ion is amenable to precipitation.  
x - indicates the process is applicable for the metal ion removal.  
T - indicates the process may be applicable for the metal ion removal. Bench scale or pilot studies are not available for confirmation.

Source: United States Environmental Protection Agency, CERCLA Site Discharges to POTWS Treatability Manual, USEPA 540/2-90-007, August 1990.

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**SOURCE:**

A Handbook on Treatment of  
Hazardous Waste Leachate (U.S. EPA, 1988)

FIGURE C-4  
SOLUBILITY DIAGRAM

## 5. Residual Handling.

5.1 Treated Material Handling. Treated material will be transported from the treatment unit to a treated material discharge area by a conveyor belt system. The treated material will be considered contaminated until laboratory analysis confirms that the material has been treated to within specified cleanup standards. The treated material discharge area should be designed to prevent cross-contamination. Possible cross-contamination scenarios include: storm water causing the leaching of contaminants the underlying soil, storm water runoff carrying contaminated material to the surrounding areas, and contaminated material being blown to surrounding areas by the wind. Common designs used to prevent cross-contamination implement some combination of the following; HDPE lining, concrete slabs, sumps connected to the water treatment plant, impermeable covers, berms, silt fencing and hay bales.

If laboratory analysis indicate that the treated material does not meet treatment requirement for organics, the material will be handled as contaminated and fed through the treatment unit again. The treated material discharge area would then need to be decontaminated before sending more treated material to it. The evaluation of treated material should include a review of all inorganic analyses of the waste.

Various guide specifications addressing layers and features of landfill construction. For example CEGS 02445: Solidification/Stabilization of Contaminated Material addresses further treatment that may be necessary prior to placement.

If laboratory analysis indicates that the treated materials meet cleanup standards, the treated material will be brought to the backfill area or treated material stockpile area. To allow the treatment unit to operate continuously, more than one treated material discharge area is required. While waiting for analytical results on treated material in one discharge area, the treatment unit could be discharging into another area. If the treated material fails TCLP requirements then, it may need to be treated (stabilization and/or solidification) prior to backfilling.

5.2 Particulate Dust Control System. The particulate matter both from the cyclone and the baghouse is managed based on the concentration of organics and inorganic compounds. If the particulate matter contains organics, it is then generally recycled through the unit for reprocessing. If the particulate matter removed by air pollution control equipment does not contain organic constituents, it can either be backfilled on site, treated to immobilize inorganic constituents, or disposed

offsite (dependent on inorganic concentrations of particulate matter). Particulate management varies from site to site. Therefore, the evaluation of particulate management should also include a review all inorganic analyses of the waste.

5.3 Clean Off-Gas. After treatment in the thermal desorption unit, the clean off-gas is discharged to the environment.

5.4 Spent Carbon. On some projects, spent carbon units in excess of 4530 kg (10,000 lb) can be sent back to the vendor for regeneration. In the event the vendor is not capable of accepting the carbon then the carbon must be disposed at an approved facility. Typically, projects and units using less than 4530 kg (10,000 lb) canisters are not regenerated.

5.5 Ion Exchange Residuals and Backwash Water. After saturation of the ion exchange resins, backwashing/ regeneration of the resin is necessary to remove the undesirable ions from the resin. Regeneration solution generally consist of acids or bases. The regenerant is classified as a liquid hazardous waste and must be disposed of in an appropriate manner. Depending on the duration of the project, the resin may need to be changed out when regeneration is no longer effective.

5.6 Oversized Material Management. If the oversized material is hazardous a pug mill or crusher can process large stones and aggregate prior to thermal treatment. Boards, plastic, and miscellaneous debris can be decontaminated and sent to a solid waste landfill for disposal. The liquid generated and residue can be treated in the wastewater treatment plant.

If the oversize material is nonhazardous, all oversized material can be sent off-site for disposal in a solid waste landfill.

5.7 Condensate. If condensers are used to treat off gas, both concentrated contaminants and wastewater are generated. The vaporized organic contaminants are condensed. A gravity decanter or a centrifugal device facilitates separation of the condensate into water and organic phases yielding a concentrated liquid. The concentrated organic liquids are then sent to a recycler for reclamation or disposed of by incineration, typically off-site. Recycling or additional treatment is generally required prior to disposal of the water phase in a wastewater treatment plant.